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ANALYSIS OF FREQUENCY SELECTIVE STRUCTURES WITH FRACTAL ELEMENTS

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ABSTRACT

It is shown the possibility of development of multifrequency frequency selective surfaces (fss) by means of complicating of the shape of elements, for example, using elements with composite fractal shape. In the paper the method of integral equations is applied for the analysis of scattering characteristic of these gratings. In the paper the possibility of applying of ffs with elements of the composite shape at development of multifrequency fss with reduced angular sensitivity on the basis of numerical experiment is shown. The obtained results can be used for choosing the most rational version of element shape of fss at a solution of some problems in antenna engineering.

INTRODUCTION

The frequency selective structures usually apply to ensure operation on many frequencies of reflective type antennas with several feeds [1]. The multifrequency frequency selective gratings are usually multilayer structures. However, to operate on several frequencies frequency selective gratings it is not necessary should be multilayer structures. The constructions of antennas with radiators, which have the shape of fractals, are known. Such antennas can operate at once on several frequencies [2]. In a paper [3] the frequency selective structure, which is composed from the fractal elements, is represented. The elements of this frequency selective structure have the shape of Sierpinski gasket.

The purpose of the present work is the numerical analysis of scattering characteristics of frequency selective structures as gratings of metal plates and slots in the perforated screens, which have the fractal shape.

THEORY

The mathematical model foundation for the frequency selective structures is made in accordance with the concept of infinite periodic arrays. Such approach is reasonable because of consideration the multielement arrays with rather complicated element structure. An alternative way of modelling may be based on the basis of so called "element by element method" with taking into account mutual coupling between array elements. This way may become much more difficult because of necessity to solve large sized system of integral equations.

The frequency selective structure is excited by plane electromagnetic wave. This plane electromagnetic wave has linear polarization. We enter to Cartesian system of coordinates. We direct axis Oz along the normal vector by the plane, where printed elements of the frequency selective structure are located. We assume that these printed elements have arbitrary shape. The steps of array along axes Ox and Oy equal accordingly d_1 and d_2. The permittivity of substrate is ε . The substrate represents the

flat layer, on obverse surface of which (plane $z = 0$) there are printed the array elements. It is necessary to determine the current distribution on the radiators of array, scattering polarizing, frequency and angular characteristic of the array.
The boundary problem was solved by integral equation method. The equation is made on the basis of Lorentz's lemma in integrated form. The application of periodicity condition has allowed to reduce the solution to search of currents within the limits of one Floquet channel. The integral equation solution is produced by moment method. The array aperture magnetic current surface density is approximated by set of subsectional current functions. In this case the rooftop functions are useful. The currents obtained from integral equations system solution allow to determine all main performances of periodic printed frequency selective structure. Therefore, one can vary the mentioned secondary parameters of the printed frequency selective structure. It is convenient to use such a procedure in the interactive mode. In a number of cases, the processes can be made automatic by means of numerical optimization of some goal function reflecting the proximity of the synthesized parameters of the frequency selective structure to the given values.

NUMERICAL RESULTS

The first example of the numerical analysis is a solution of the diffraction problem of a plane electromagnetic wave on a periodic grating, which is composed from fractal dipoles. The dipoles are composed from two triangles. The shape of these triangles is Sierpinski triangle [2]. To create this geometric fractal the following algorithm is used. Let's take a triangular metal plate. Let middles of legs of this triangle are tops of a new triangle. This new triangle we shall delete from an initial triangle. It is clear, that the created now structure consists of three triangles. The sizes of these triangles twice are less than sizes of an initial triangle. In the further process of deleting of metal from the stayed triangular elements repeats similarly. The fractal element of N generation will be generated after a termination of N steps of this algorithm.
The unit cell of a periodic grating, which is composed from such printed dipoles, is shown in Fig.1,a. The single dipole of this frequency selective structure consists of two Sierpinski.

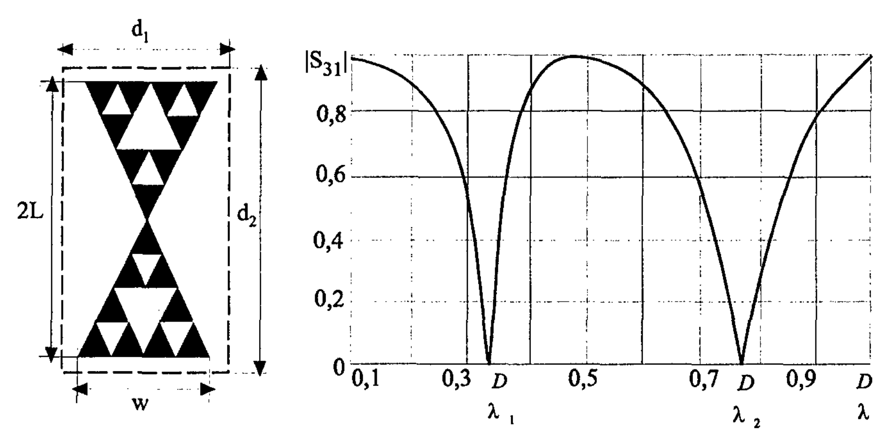

Fig. 1

triangles. These triangles are fractals of second generation. It is shown that the fractal element represents a self-similar structure, in which each triangular fragment represents a duplicate in the reduced scale of all fractal structure in whole. Here is designated: L =

7 mm — length of a dipole shoulder; W = 13 mm — foundation of a triangle; $d_1 = d_2 =$ 15 mm — sizes of a grating unit cell. The frequency selective structure is excited by a plane electromagnetic wave with linear polarization. The vector of polarization of an excited wave is directed along axis of printed dipoles. The calculated frequency characteristic of an electromagnetic wave transition factor by such fractal frequency selective structure in case of co-polarization is shown in a fig. 1,b. It is shown, there are two resonances of a full reflection, when $2L/\lambda_1 = 0{,}32$ and $2L/\lambda_2 = 0{,}72$ in a single-wave range of a grating. The ratio of upper frequency of a rejection to the lower frequency is equal $\zeta = 2{,}25$. It is important to notice, that as against [3], in the given example the dipoles are located in knots of a grid with a rectangular cell. In a paper [3] the case has been considered, when the similar fractal dipoles locate in knots of a grid with a triangular mesh. The ratio of rejection frequencies in this case is equal $\zeta = 2{,}9$.

Thus, the printed frequency selective structure composed from fractal dipoles has a property of a two-frequency rejection in a single-wave range of a grating.

In further we shall consider performances of scattering of the perforated screens. Now, as against a grating of plates, in the perforated screen on some (resonance) frequencies the phenomenon of incident electromagnetic wave full transition is observed. It is possible to create a mode of full transition of electromagnetic waves through perforated screen at once on several frequencies. The realization such slots in the perforated screen, which have shape of fractal, will allow to achieve full transition electromagnetic wave on several frequencies.

To check up a validity of this supposition such perforated screen is researched, in which slots have the shape of Sierpinski square. The perforated screen is considered, in which the slots are located so that the unit cell of a grating had the shape of Sierpinski square of second generation. The topology of a grating unit cell is shown in insertion of Fig.2.

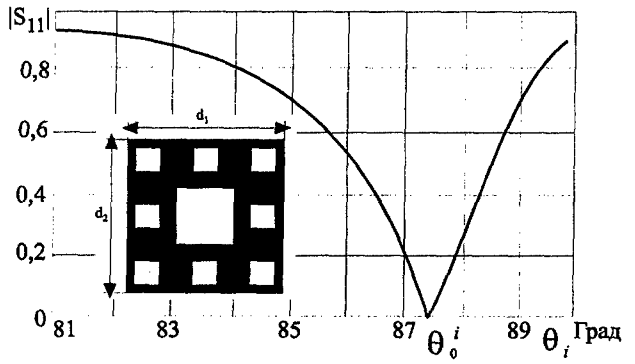

Fig. 2

The grating unit cell has following sizes: $d_1 = d_2 = 10$ mm. If such perforated screen is excited by normal incident plane electromagnetic wave, then resonances are not present in single-wave range of an array periodicity, because the sizes of square slots in a screen are unsufficiently great. However, in case of an electromagnetic wave sloping incidence on a grating it is possible to observe effect of full transition of electromagnetic waves through such a frequency-selective structure. The relationship of reflection factor of an electromagnetic wave with parallel polarization in a sector of incidence angle close to a "sliding" incidence is shown in Fig.2. This characteristic has been calculated in a case, when $f = 15$ GHz. It is shown, that the resonance of full transition is observed with $\theta_0^i = 87{,}4°$. Thus it is necessary to notice, that as shown in [5], the screen with identical square slots has not resonances of full transition in an angular sector from normal incidence down to a "sliding" incidence of an electromagnetic

waves.

Thus, the modification of a unit cell shape of the perforated screen has reduced to emerging scattering modes of electromagnetic waves, which are not typical for frequency selective structures composed from simple (not fractal) elements.

To achieve full transition of electromagnetic waves through the perforated screen, not only with sloping, but also with a normal electromagnetic wave incidence, it is necessary, that slots in a screen would have resonance sizes in a single-wave range of a grating. For example, the application of crosslike slots allows to create a mode of a full transition of electromagnetic waves through a screen also with a normal electromagnetic wave incidence [5]. By replacing square slots in Sierpinski fractal to crosslike slots we achieve necessary increasing of slots sizes down to resonance in a single-wave range of a grating. The size of a unit cell remains same, as in the previous example. The frequency characteristic of reflection factor of such perforated screen is shown in Fig. 3.

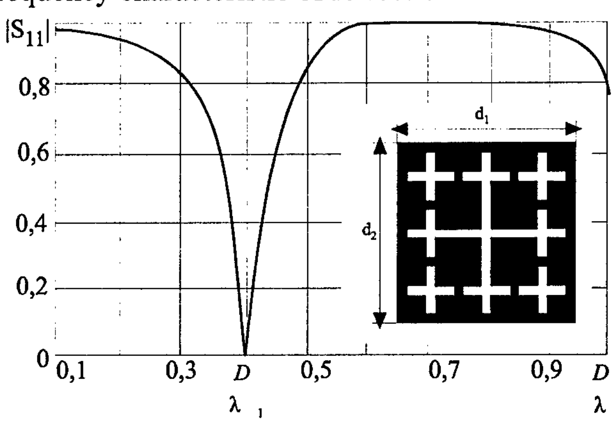

Fig. 3

It is shown, the unique resonance of full transition of electromagnetic wave through frequency-selective surface is observed in a single-wave range of wavelengths with D/λ_1 . Two-frequency mode of an electromagnetic wave transition such frequency selective surface does not ensure, because only central crosslike slots, which have large arm length "resonate" in a single-wave range of a grating. At the same time resonance frequencies of peripheral crosslike slots locate in a multimode range of a grating, therefore these slots do not influence to transition of an electromagnetic wave through the perforated screen in a single-wave range of an array. It is necessary to notice, that the similar result was obtained in paper [6]. In this paper the perforated screen as a periodic grating of slots was investigated. The shape of each slot of this grating is Jerusalem cross. Jerusalem cross is enclosed by simple crosslike slots, is similar to that is represented in insertion of Fig.3.

Thus, for reaching multifrequency mode of operations of the perforated screen it is necessary, that all slots were resonance in a single-wave range of a grating.

Last numerical example connects with the perforated screen, which unit cell has a topology shown in Fig.4, a. This grating has following parameters: L_1 = 13,4 mm; L_2 = 7 mm. The size of a unit cell is same, as well as in two previous examples. The grating is excited by a plane electromagnetic wave of linear polarization. The normal incidence of electromagnetic wave is considered. The vector of electromagnetic wave polarization is directed along a diagonal of square, which limits a unit cell of the perforated screen. The frequency characteristic of a reflection factor of this frequency selective structure is shown in Fig. 4, b. It is shown, that such grating has two resonance frequencies in a single-wave range of array. These frequencies are just those frequencies, on which the full transition of an electromagnetic wave through the perforated screen is observed. If

D/λ_1 is equal 0,37, then the long wavelength resonance is observed. It is shown, that in this case L_1/λ_1 is equal 0,5. If D/λ_2 is equal 0,67, then the short-wave resonance is observed. It is shown, that in this case L_2/λ_2 is equal 0,475. So, it is possible to make a conclusion that a long wavelength resonance "ensure" longer slots (central slot of a unit cell of the perforated screen), and a short-wave resonance "ensure" more short, that is peripheral, slots.

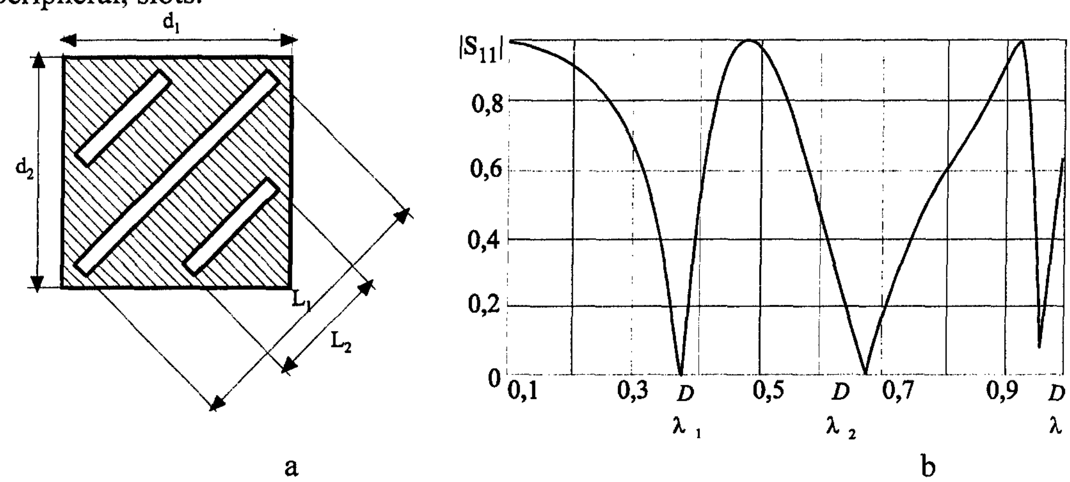

Fig. 4

Thus, if the frequency selective structure is the perforated screen, which consists of fractal slots, then this structure has a property of electromagnetic wave transition on two frequencies in a single-wave range of a grating.

CONCLUSION

Basing on numerical experiment, in a paper it is shown the possibility to use printed arrays with the fractal elements for development of two-frequency electrodynamic frequency selective structures. These results can be used for a choice of the most rational variant of a frequency-selective structure geometry for a solution of the some problems of an antenna engineering.

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